Lake and Wetland Monitoring Program

1998 Annual Report

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Executive Summary

The Kansas Department of Health and Environment (KDHE) Lake and Wetland Monitoring Program surveyed the water quality conditions of 36 Kansas lakes during 1998, plus 17 wetland areas that are part of a special study scheduled for completion in 2001. Fourteen of the lakes surveyed in 1998 were large federal impoundments, seven were State Fishing Lakes (SFLs), and the remaining 15 were city and county lakes.

Of the 36 lakes surveyed, 28% indicated reasonably constant trophic state conditions since their last water quality survey. Another 28% indicated improved water quality conditions as the result of lowered lake trophic state. The remaining 42% indicated degraded water quality as the result of increasing lake trophic state conditions. One lake was new to the network and had no past data with which to compare. Phosphorus was identified as the primary limiting factor in 67% of the lakes surveyed during 1998. Nitrogen was identified as the primary limiting factor in 14% of the lakes, while 17% were identified as primarily light limited.

There were a total of 122 documented exceedences of Kansas numeric and narrative water quality criteria, or Environmental Protection Agency (EPA) water quality guidelines, during 1998. Of these 122 exceedences, 27% were concerning the aquatic life use, and 73% concerned consumptive and recreational uses. Fully 66% involved uses previously designated for those lakes in the Kansas Surface Water Register. The other 34% were for uses that had not yet been formally designated or verified by use attainability analyses.

Twenty lakes (56%) had detectable levels of at least one pesticide in their main bodies during 1998. Atrazine was detected in all 20 of these lakes, once again making it the most commonly documented pesticide in Kansas surface waters. Only one of the lakes surveyed in 1998 exceeded the interim chronic aquatic life support criterion for atrazine. A total of six different pesticides, and one pesticide degradation byproduct, were found in lakes during 1998.

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INTRODUCTION

Development of the Lake and Wetland Monitoring Program

The Kansas Department of Health and Environment (KDHE) Lake and Wetland Monitoring Program was established in 1975 to fulfill the requirements of the 1972 Clean Water Act (Public Law 92-500) by providing Kansas with background water quality data for water supply and recreational impoundments, by determining regional and time trends for those impoundments, and by identifying pollution control and/or assessment needs within individual lake watersheds.

Program activities originally centered around a small sampling network comprised mostly of federal lakes, with sampling stations at numerous locations within each lake. In 1985, based on the results of statistical analyses conducted by KDHE, the number of stations per lake was reduced to a single station within the main body of each impoundment. This, and the elimination of parameters with limited interpretive value, allowed expansion of the lake network to its present 115 sites scattered throughout all the major drainage basins and physiographic regions of Kansas. The program remains dynamic, with lakes occasionally being dropped from active monitoring and/or replaced with more appropriate sites throughout the state.

In 1989, KDHE initiated a Taste and Odor/Algae Bloom Technical Assistance Program for public drinking water supply lakes. This was done to assist water suppliers in the identification and control of taste and odor problems in finished drinking water that result from lake ecological proccsses and algae blooms.

Overview of the 1998 Monitoring Activities

Staff of the KDHE Lake and Wetland Monitoring Program visited 36 Kansas lakes during 1998. Fourteen of these lakes are large federal impoundments last sampled in 1995 or as part of the Governor's Water Quality Initiative in the Kansas River Basin, seven are state fishing lakes (SFLs), and the remaining fifteen are city/county lakes (Cls and Co. lakes, respectively). Twenty-three of the 36 lakes serve as either primary or back-up municipal and/or industrial water supplies.

As part of the Governor's Water Quality Initiative in the Kansas/Lower Republican River Basin, seven lakes were targeted for sampling on an annual basis during 1996-1998. These lakes include Tuttle Creek, Milford, Clinton, and Perry Lakes, all ultimately feeding into the Kansas River. Also included are three smaller lakes within targeted watersheds in the Black Vermillion River Basin upstream from Tuttle Creek Lake (Centralia Lake) and the Grasshopper Creek Basin upstream of Perry Lake (Mission Lake and Atchison County Lake).

As part of an Environmental Protection Agency (EPA) funded study, 17 public wetland areas will be surveyed each year from 1997 to 2000. These include the seven public wetland areas that are part of the Lake and Wetland Monitoring Program network. The purpose of this study is to produce a baseline picture of water quality conditions in Kansas wetlands. Results from this four year sampling effort will be summarized in a final project report scheduled for completion in 2001.

Some general information on the lakes surveyed during 1998 is compiled in Table 1. Figure 1 depicts the locations of the 36 lakes surveyed during 1998. Figure 2 depicts the locations of all currently active sites within the Lake and Wetland Monitoring Program. In addition to routine monitoring, a total of five lakes, streams, and ponds were investigated as part of the Taste and Odor/Algae Bloom Technical Assistance Program.

Created lakes are usually termed "reservoirs" or "impoundments," depending on whether they are used for drinking water supply or for other beneficial uses, respectively. In many parts of the country, smaller lakes are termed "ponds" based on arbitrary surface area criteria. To provide consistency, this report uses the term "lake" to describe all non-wetland bodies of standing water within the state. The only exception to this is when more than one lake goes under the same general name. For example, the City of Herington has jurisdiction over two larger lakes. The older lake is referred to as Herington City Lake while the newer one is called Herington Reservoir in order to distinguish it from its sister waterbody.

METHODS

Yearly Selection of Monitored Sites

Since 1985, the 24 large federal lakes in Kansas have been arbitrarily partitioned into three groups of eight. Each group is, normally, sampled once during a three year period of rotation. Up to 30 smaller lakes are sampled each year in addition to that year's block of eight federal lakes. These smaller lakes are chosen based on three considerations: 1) Is there recent data available (within the last 3-4 years) from KDHE or other programs?; 2) Is the lake showing indications of pollution that require enhanced monitoring?; or 3) Have there been water quality assessment requests from other administrative or regulatory agencies (state, local, or federal)? Several lakes have been added to the network due to their relatively unimpacted watersheds. These lakes serve as ecoregional reference sites.

Sampling Procedures

At each lake, a boat is anchored over the inundated stream channel near the dam. This point is referred to as Station 1, and represents the area of maximum depth. Duplicate water samples are taken by Kemmerer sample bottle at 0.5 meters below the surface for determination of inorganic chemistry (basic cations and anions), algal community composition, chlorophyll-a, nutrients (ammonia, nitrate, nitrite, Kjeldahl nitrogen, and total and ortho phosphorus), and metals/metalloids (aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, thallium, vanadium, and zinc). Duplicate water samples are also taken at 0.5-to-1.0 meters above the lake substrate for determination of inorganic chemistry, nutrients, and metals/metalloids within the hypolimnion. In addition, a single pesticide sample, and duplicate bacterial (fecal coliform and fecal streptococci) samples, are taken at 0.5 meters depth at the primary sampling area (KDHE, 1995).

Table 1. General information pertaining to lakes surveyed during 1998.

Lake	Basin	Authority	Water Supply	Last Survey
Atchison Co. Lake	Kansas	County	no	1997
Augusta City Lake	Walnut	City	yes	1991
Banner Creek Lake	Kansas	County	yes	new
Big Hill Lake	Verdigris	Federal	yes	1995
Cedar Creek Lake	Marais des Cygnes	City	yes	1993
Centralia Lake	Kansas	City	no	1997
Cheney Lake	Lower Arkansas	Federal	yes	1996
Clinton Lake	Kansas	Federal	yes	1997
Council Grove City Lake	Neosho	City	yes	1994
Douglas Co. SFL	Kansas	State	no	1994
Elk City Lake	Verdigris	Federal	yes	1995
Fall River Lake	Verdigris	Federal	yes	1995
Gardner City Lake	Kansas	City	yes	1993
Geary Co. SFL	Smoky Hill/Saline	State	no	1994
Hamilton Co. SFL	Upper Arkansas	State	no	1997
Harvey Co. East Lake	Walnut	County	no	1994
Hillsdale Lake	Marais des Cygnes	Federal	yes	1997
Kirwin Lake	Solomon	Federal	no	1995
Lake Crawford	Marais des Cygnes	State	no	1993
Lovewell Lake	Kansas	Federal	no	1995
Lyon Co. SFL	Marais des Cygnes	State	no	1994
Madison City Lake	Verdigris	City	yes	1993
Milford Lake	Kansas	Federal	yes	1997
Mission Lake	Kansas	City	yes	1997
Moline City Lake #2	Verdigris	City	yes	1993

Lake	Basin	Authority	Water Supply	Last Survey
Norton Lake	Upper Republican	Federal	yes	1995
Olpe City Lake	Neosho	City	no	1991
Perry Lake	Kansas	Federal	yes	1997
Pottawatomie Co. SFL #1	Kansas	State	no	1994
Pottawatomie Co. SFL #2	Kansas	State	no	1994
Sedan North Lake	Verdigris	City	yes	1993
Thayer New Lake	Verdigris	City	yes	1993
Toronto Lake	Verdigris	Federal	yes	1995
Tuttle Creek Lake	Kansas	Federal	yes	1997
Waconda Lake	Solomon	Federal	yes	1995
Yates Center Lake	Verdigris	City	yes	1994

At each lake, measurements are made at Station 1 for temperature and dissolved oxygen profiles, field pH, and Secchi disk depth. All samples are preserved and stored in the field in accordance with KDHE Quality Assurance/Quality Control protocols (KDHE, 1995). Field measurements, chlorophyll-a analyses, and algal taxonomic determinations are conducted by staff of KDHE's Bureau of Environmental Field Services. All other analyses are carried out by the KDHE Health and Environmental Laboratory (KHEL) (KDHE, 1995).

Since 1992, macrophyte surveys have been conducted at each of the smaller lakes (<300 acres) within the KDHE Lake and Wetland Monitoring Program network. These surveys initially entail the selection of 10-to-20 sampling points (depending on total surface area and lake morphometry), plotted on a field map in a regular pattern over the lake surface. At each sampling point, a grappling hook is cast to rake the bottom for submersed aquatic plants. This process, combined with visual observations at each station, confirms the presence or absence of macrophytes at each station. If present, macrophyte species are identified and recorded on site. Those species that can't be identified in the field are placed in plastic bags, on ice, for identification at the KDHE Topeka office. Presence/absence data, and taxon specific presence/absence data, are used to calculate a "percent distribution" estimate for each lake (KDHE, 1995).

Figure 1. Locations of the 36 lakes surveyed during 1998.

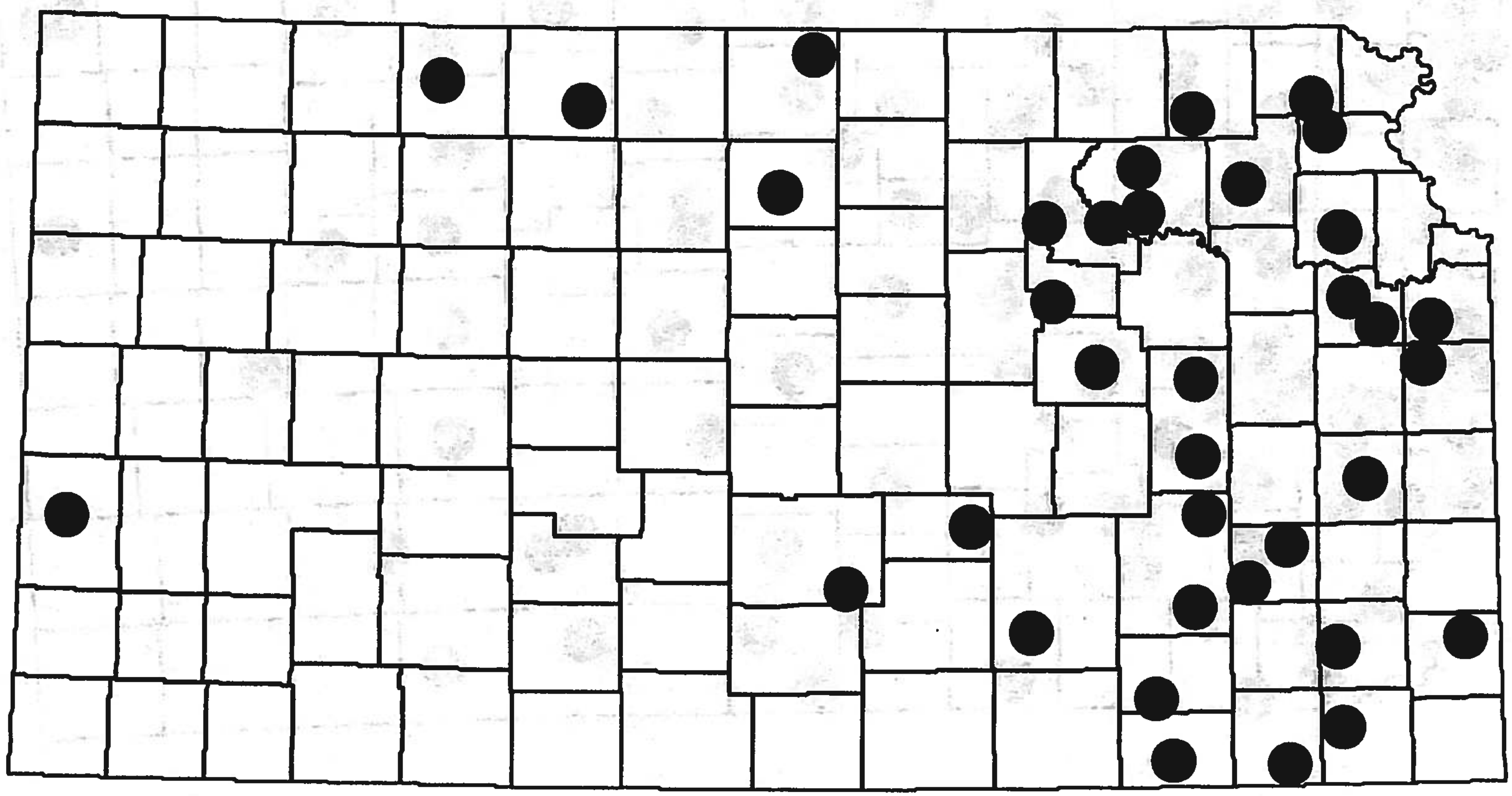
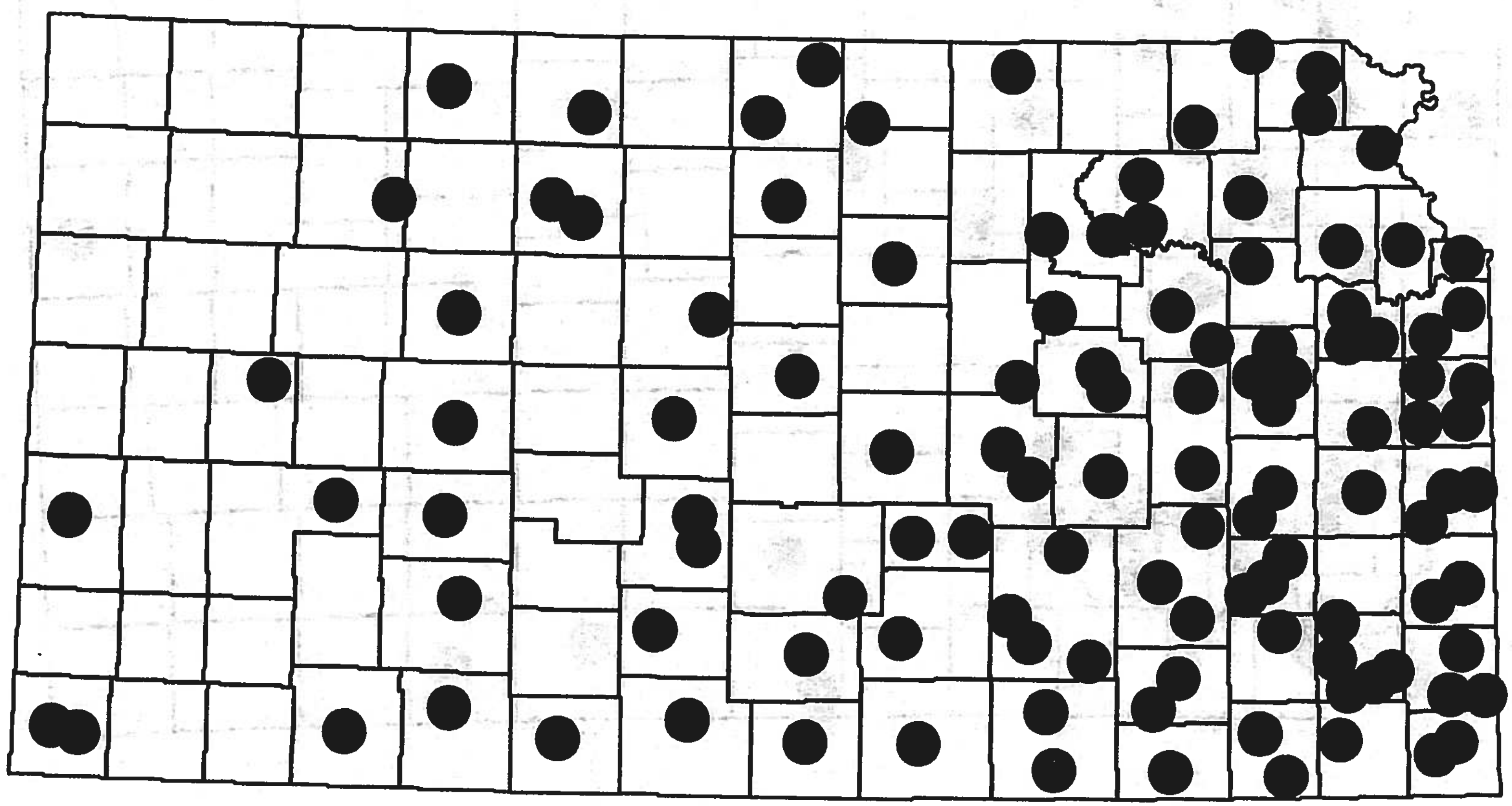


Figure 2. Locations of all currently active lake and wetland sampling sites within the KDHE Lake and Wetland Monitoring Program.



Taste and Odor/Algae Bloom Program

In 1989, KDHE initiated a formal Taste and Odor/Algae Bloom Technical Assistance Program. Technical assistance concerning taste and odor incidences in water supply lakes, or algae blooms in lakes and ponds, may take on varied forms. Investigations may simply involve identification of algal species present within a lake, or they may entail the measurement of numerous physical, chemical, or biological parameters including watershed land use analysis to identify nonpoint pollution sources. Investigations are generally initiated at the request of water treatment plant personnel, or personnel at the KDHE District Offices. While lakes used for public water supply are the primary focus, a wide variety of samples related to algae, odors, and fishkills, from both lakes and streams, are accepted for analysis.

RESULTS AND DISCUSSION

Lake Trophic State

The Carlson Chlorophyll-a Trophic State Index (TSI) remains a useful tool for the comparison of lakes in regard to general ecological functioning and level of productivity (Carlson, 1977). Table 2 presents TSI scores for the 36 lakes surveyed during 1998, previous TSI scores for those lakes with past data, and an indication of the extent that lake productivity is dominated by submersed and floating-leaved vascular plant communities (macrophytes). Since chlorophyll-a TSI scores are based on the planktonic algae community, production due to macrophyte beds is not reflected in these scores. The system used to assign lake trophic state, based on TSI scores, is presented below. Trophic state classification is adjusted for macrophytes where percent areal cover (as estimated by percent presence) is greater than 30%, and visual bed volume and plant density clearly indicate that macrophyte productivity contributes significantly to overall lake primary production.

TSI score of 0-39 = oligo-mesotrophic (OM)

> OM = A lake with a low level of planktonic algae. Such lakes also lack significant amounts of suspended clay particles in the water column, giving them a relatively high level of water clarity. Chlorophyll-a averages ≤ 2.5 ug/L.

TSI score of 40-49 = mesotrophic (M)

> M = A lake with only a moderate planktonic algal community. Water clarity remains relatively high. Chlorophyll-a ranges from 2.51-to-7.2 ug/L.

TSI score of 50-63 = eutrophic (E)

E = A lake with a moderate-to-large algae community. Chlorophyll-a ranges from 7.21-to-30.0 ug/L. This category is further divided as follows:

TSI = 50-54 = slightly eutrophic (SE)	Chlorophyll-a ranges 7.21-to-12.0 ug/L,
TSI = 55-59 = fully eutrophic (E)	Chlorophyll-a ranges 12.01-to-20.0 ug/L,
TSI = 60-63 = very eutrophic (VE)	Chlorophyll-a ranges 20.01-to-30.0 ug/L.

TSI score of ≥64 = hypereutrophic (H)

H = A lake with a very large phytoplankton community. Chlorophyll-a averages >30.0 ug/L. This category is further divided as follows:

TSI = 64-69.9 = lower hypereutrophic	Chlorophyll-a ranges 30.01-to-55.99 ug/L,
TSI = ≥70 = upper hypereutrophic	Chlorophyll-a ranges ≥56 ug/L.

TSI score not relevant = argillotrophic (A)

A = In a number of Kansas lakes, high turbidity due to suspended clay particles restricts the development of a phytoplankton community. In such cases, nutrient availability remains high, but is not fully translated into algal productivity or biomass due to light limitation. Lakes with such high turbidity and nutrient levels, but lower than expected algal biomass, are called argillotrophic (Naumann, 1929) rather than oligo-mesotrophic, mesotrophic, etc. These lakes may have chronic high turbidity, or may only experience sporadic (but frequent) episodes of dis-equilibria following storm events that create "over flows" of runoff on the lake surface. Argillotrophic lakes also tend to have very small, or nonexistent, submersed macrophyte community. Mean chlorophyll-a remains ≤7.2 ug/L.

All Carlson chlorophyll TSI scores are calculated by the following formula, where C is the phaeophytin corrected chlorophyll-a level in ug/L (Carlson, 1977):

$$TSI = 10(6-(2.04-0.68\log_e(C))/\log_e(2)).$$

The composition of the algal community (structural feature) often gives a better ecological picture of a lake than relying solely on a trophic state classification (functional feature). Table 3 presents both total algal cell count and percent composition of several major algal groups for the lakes surveyed in 1998. Lakes in Kansas that are nutrient enriched tend to be dominated by green or blue-green algae, while those dominated by diatom communities may not be so enriched. Certain species of blue-green, diatom, or dinoflagellate algae may contribute to taste and odor problems in finished drinking water, when present in large numbers in lakes and streams.

Table 4 presents biovolume data for the 36 lakes surveyed in 1998. When compared to cell counts, such data are useful in determining which species or algae groups actually exert the strongest ecological influence on a lake.

Table 2. Current and past TSI scores, and trophic state classification for the lakes surveyed during 1998. Trophic class abbreviations used previously apply. An asterisk appearing after the lake name indicates that the lake was dominated by macrophyte production. In such a case, the 1998 trophic class is adjusted, and the adjusted trophic state class given in parentheses. Previous TSI scores are based only on algal chlorophyll TSI score.

Lake	1998 TSI/Class	Previous Trophic Class
Atchison Co. Lake	68.0 H	E
Augusta City Lake	63.3 VE	H
Banner Creek Lake	59.1 E	unknown
Big Hill Lake	53.0 SE	M
Cedar Creek Lake	65.2 H	SE
Centralia Lake	74.7 H	H
Cheney Lake	45.9 A	A
Clinton Lake	64.3 H	E
Council Grove City Lake	52.3 SE	M
Douglas Co. SFL	63.9 VE	SE
Elk City Lake	53.2 SE	VE
Fall River Lake	55.5 E	SE
Gardner City Lake	54.5 SE	H
Geary Co. SFL	55.5 E	SE
Hamilton Co. SFL *	68.6 H (H)	E
Harvey Co. East Lake	73.5 H	H
Hillsdale Lake (whole lake) $	61.8 VE $	H $
Hillsdale Lake Station 1 (main body)	55.3 E	SE
Hillsdale Lake Station 2 (Big Bull Arm)	66.0 H	H

Lake	1998 TSI/Class	Previous Trophic Class
Hillsdale Lake Station 3 (Little Bull Arm)	61.2 VE	SE
Kirwin Lake	56.4 E	VE
Lake Crawford	57.4 E	SE
Lovewell Lake	55.9 E	E
Lyon Co. SFL	52.2 SE	SE
Madison City Lake	54.4 SE	E
Milford Lake	56.8 E	SE
Mission Lake	60.7 VE	H
Moline City Lake #2 *	43.3 M (SE)	M
Norton Lake	55.5 E	M
Olpe City Lake	53.8 SE	VE
Perry Lake	58.9 E	E
Pottawatomie Co. SFL #1 *	56.1 E (VE)	M
Pottawatomie Co. SFL #2 *	44.5 M (SE)	M
Sedan North Lake *	50.0 SE (E)	VE
Thayer New Lake	36.8 OM	M
Toronto Lake	60.2 VE	E
Tuttle Creek Lake	43.0 A	A
Waconda Lake	62.3 VE	H
Yates Center Lake *	51.7 SE (E)	SE

$ = Hillsdale Lake represents a special case as the whole lake TSI is the mean of three individual stations within the lake. Historically, this lake has sat on the boundary between slightly and fully eutrophic. The last two years have seen significant increases in trophic state at Hillsdale Lake.

Table 3. Algal communities observed in the 36 lakes surveyed during 1998. The "other" category refers to euglenoids, cryptophytes, dinoflagellates, and other single-celled flagellate forms of algae.

	Cell Count	Percent Composition			
Lake	**(cells/mL)**	**Green**	**Blue-Green**	**Diatom**	**Other**
Atchison Co. Lake	72,419	17	56	25	2
Augusta City Lake	9,860	10	7	76	7
Banner Creek Lake	130,725	0	100	0	0
Big Hill Lake	18,995	5	84	7	4
Cedar Creek Lake	37,832	17	25	54	4
Centralia Lake	188,591	0	99	1	0
Cheney Lake	2,817	56	33	0	11
Clinton Lake	14,616	37	20	25	18
Council Grove CL	20,475	6	85	5	4
Douglas Co. SFL	223,209	0	99	1	0
Elk City Lake	2,867	12	0	54	34
Fall River Lake	6,363	14	30	48	8
Gardner City Lake	25,862	14	74	3	9
Geary Co. SFL	18,837	34	45	20	1
Hamilton Co. SFL	14,616	24	0	18	58
Harvey Co. East Lake	212,531	2	89	8	1
Hillsdale Lake Sta. 1	4,284	46	0	25	29
Hillsdale Lake Sta. 2	29,232	2	55	3	40
Hillsdale Lake Sta. 3	11,907	7	40	6	47
Kirwin Lake	71,757	4	94	1	1
Lake Crawford	25,673	18	56	19	7
Lovewell Lake	4,032	50	0	34	16
Lyon Co. SFL	12,159	14	50	22	14
Madison City Lake	3,056	4	0	60	36
Milford Lake	9,041	34	50	3	13

Lake	Cell Count (cells/mL)	Percent Composition Greens	Blue-Greens	Diatoms	Other
Mission Lake	26,429	46	46	7	1
Moline City Lake #2	1,292	62	0	14	24
Norton Lake	35,942	22	75	2	1
Olpe City Lake	2,804	36	21	43	0
Perry Lake	13,388	52	0	22	26
Pott. Co. SFL #1	7,749	46	0	51	3
Pott. Co. SFL #2	4,095	78	22	0	0
Sedan North Lake	5,355	52	11	14	23
Thayer New Lake	2,426	45	53	1	1
Toronto Lake	5,040	20	0	43	37
Tuttle Creek Lake	1,922	21	66	10	3
Waconda Lake	14,837	14	32	1	53
Yates Center Lake	4,473	27	35	21	17

Table 4. Algal biovolumes calculated for the lakes surveyed during 1998. The "other" category refers to euglenoids, cryptophytes, dinoflagellates, and other single-celled flagellate forms of algae. Biovolume units are calculated in mm^3/L, and expressed as parts-per-million (ppm).

Lake	Biovolume (ppm)	Percent Composition Green	Blue-Green	Diatom	Other
Atchison Co. Lake	56.032	12	20	56	12
Augusta City Lake	18.838	4	2	83	11
Banner Creek Lake	69.829	0	100	0	0
Big Hill Lake	15.655	5	60	22	13
Cedar Creek Lake	48.928	10	6	70	14
Centralia Lake	78.452	0	96	4	0
Cheney Lake	1.497	31	24	0	45

Lake	Biovolume (ppm)	Percent Composition			
		Green	Blue-Green	Diatom	Other
Clinton Lake	43.044	8	3	33	56
Council Grove CL	9.302	4	55	25	16
Douglas Co. SFL	60.478	0	99	1	0
Elk City Lake	9.178	1	0	30	69
Fall River Lake	12.696	1	4	72	23
Gardner City Lake	10.409	19	38	18	25
Geary Co. SFL	11.482	14	31	50	5
Hamilton Co. SFL	46.181	6	0	18	76
Harvey Co. East Lake	63.945	3	57	34	6
Hillsdale Lake Sta. 1	5.025	19	0	38	43
Hillsdale Lake Sta. 2	21.148	1	22	8	69
Hillsdale Lake Sta. 3	10.449	7	14	10	69
Kirwin Lake	18.447	7	58	8	27
Lake Crawford	17.241	15	18	48	19
Lovewell Lake	4.556	24	0	46	30
Lyon Co. SFL	7.392	15	24	7	54
Madison City Lake	3.353	4	0	25	71
Milford Lake	5.744	10	31	13	46
Mission Lake	17.315	57	20	14	9
Moline City Lake #2	3.132	20	0	8	72
Norton Lake	14.089	27	55	7	11
Olpe City Lake	2.719	22	9	69	0
Perry Lake	21.881	11	0	44	45
Pott. Co. SFL #1	9.592	17	0	64	19
Pott. Co. SFL #2	1.165	79	21	0	0
Sedan North Lake	5.613	28	3	6	63
Thayer New Lake	0.848	62	29	4	5

Lake	Biovolume (ppm)	Percent Composition			
		Green	Blue-Green	Diatom	Other
Toronto Lake	14.646	2	0	30	68
Tuttle Creek Lake	0.885	16	29	41	14
Waconda Lake	13.176	9	8	1	82
Yates Center Lake	3.972	18	16	13	53

Trends in Trophic State

Table 5 summarizes changes in trophic status for the 36 lakes surveyed during 1998. Fifteen lakes displayed increases in trophic state since their last surveys (42%). Ten lakes, each, displayed improved or constant trophic states since the last survey (28%, each). One lake was new to the network (2%), as well as constructed fairly recently (Banner Creek Lake), and has no past data with which to compare.

As shown in Table 6, of the 17 lakes receiving macrophyte surveys 11 had detectable amounts of plant material. In these lakes, the most common plant species were several forms of pondweed (Potamogeton spp.), water naiad (Najas guadalupensis), coontail (Ceratophyllum demersum), and various species of stonewort algae (Chara spp.). Macrophyte species detected in 1998 are very similar to previous years.

The summer of 1998 was very dry, with prolonged periods of reduced rainfall and runoff. The effect of these climatologic conditions was to increase water clarity in virtually all surveyed lakes, as compared to mean water clarity from past surveys. The effect on lake trophic state was varied, indicating that light limitation is not as prevalent in Kansas waterbodies as many have presumed in the past. While some lakes did appear to have a higher trophic state than previously, a significant number had lower levels of algae in 1998. Overall, the impact of reduced nutrient loads appears more important in controlling lake trophic state.

Lake Stratification

Stratification is a natural process that may occur in any standing (lentic) body of water, whether that body is a natural lake, pond, artificial reservoir, or wetland pool (Wetzel, 1983). It occurs when sunlight (heat energy) penetrates into the water column. Due to the thermal properties of water, high levels of sunlight (combined with calm winds during the spring-to-summer months) cause layers of water to form with differing temperatures and densities. The cooler, denser layer (the hypolimnion) remains near the bottom of the lake while the upper layer (the epilimnion) develops a higher ambient temperature. The middle layer (the metalimnion) displays a marked drop in temperature with depth (the thermocline), compared to conditions within the epilimnion and hypolimnion.

Table 5. Trends over time for lake trophic state classification within each major river basin in Kansas. Banner Creek Lake is not included since there is no past data for examining trends. Only those basins visited during 1998 are included.

Basin	Number of Lakes		
	Constant	Improving	Degrading
Kansas/Lower Republican	5	2	5
Lower Arkansas	1	0	0
Marais des Cygnes *	1	0	3
Neosho	0	1	1
Smoky Hill/Saline	0	0	1
Solomon	0	2	0
Upper Arkansas	0	0	1
Upper Republican	0	0	1
Verdigris	2	4	3
Walnut	1	1	0
Total	10	10	15

* = Hillsdale Lake, within the Marais des Cygnes River Basin, represents an unusual case in that the whole lake trophic state is an average of multiple stations. While overall trophic state declined slightly since the last survey, more of the lake displayed increased trophic conditions than seen in 1997. Therefore, it is still counted as showing a degrading trophic state condition.

Once these layers of water with differing temperatures form, they tend to remain stable and do not easily mix with one another. This formation of distinct layers impedes, or precludes, the atmospheric reaeration of the hypolimnion, at least for the duration of the summer (or until ambient conditions force mixing). In many cases, this causes hypolimnetic waters to be depleted of oxygen and unavailable as habitat for fish and other aquatic life. Stratification eventually breaks down in the fall when surface waters cool. Once epilimnetic waters cool to temperatures comparable to hypolimnetic waters, the lake will mix completely once again. This, typically, fall phenomenon is called "lake turnover."

Lake turnover can cause fishkills, aesthetic problems, and taste and odor problems in finished drinking water if the hypolimnion comprises a significant volume of the lake. This is because such a sudden mixing combines oxygen-poor, nutrient-rich hypolimnetic water with epilimnetic water lower in nutrients and richer in dissolved oxygen. Lake turnover can result in explosive algae growth, lowering of overall lake oxygen levels, sudden fishkills, and often imparts objectionable odors to the lake water and tastes and odors to finished drinking water produced from the lake. Thus, the stratification process is an important facet of lake management.

Table 6. Macrophyte community structure in the 17 lakes surveyed for macrophytes during 1998. Macrophyte community refers only to the submersed and floating-leaved aquatic plants, not emergent shoreline plants. The percent species cover is the abundance estimate for each documented species (Note: due to overlap in cover, the percentages under community composition may not equal the total cover). Traditional underlining of genera and species is omitted from this table for readability.

Lake	% Total Cover	% Species Cover and Community Composition
Augusta City Lake	<10%	no species observed
Douglas Co. SFL	20%	15% *Najas guadalupensis* 7% *Potamogeton nodosus*
Gardner City Lake	<10%	no species observed
Geary Co. SFL	47%	47% *Ceratophyllum demersum* 47% *Potamogeton foliosus* 20% *Potamogeton nodosus*
Hamilton Co. SFL	100%	100% *Chara globularis* 100% *Potamogeton pectinatus*
Harvey Co. East Lake	<10%	no species observed
Lake Crawford	5%	5% *Ceratophyllum demersum*
Lyon Co. SFL	33%	33% *Najas guadalupensis* 7% *Nelumbo sp.*
Madison City Lake	<10%	no species observed
Mission Lake	<10%	no species observed
Moline City Lake #2	100%	100% *Chara canescens* 50% *Potamogeton nodosus* 40% *Najas guadalupensis*
Olpe City Lake	<10%	no species observed
Pottawatomie Co. SFL #1	70%	50% *Potamogeton foliosus* 40% *Ceratophyllum demersum* 10% *Chara braunii* 10% *Potamogeton nodosus*

Lake	% Total Cover	% Species Cover and Community Composition
Pottawatomie Co. SFL #2	87%	87% *Chara globularis* 27% *Potamogeton pusillus* 20% *Potamogeton nodosus* 13% *Najas guadalupensis* 13% *Potamogeton pectinatus* 7% *Ceratophyllum demersum* 7% *Potamogeton foliosus*
Sedan North Lake	90%	70% *Chara zeylanica* 70% *Potamogeton nodosus* 50% *Najas guadalupensis* 30% *Nelumbo sp.*
Thayer New Lake	60%	40% *Najas guadalupensis* 30% *Callitriche heterophylla*
Yates Center Lake	73%	73% *Najas guadalupensis* 67% *Potamogeton nodosus* 27% *Chara zeylanica* 13% *Potamogeton pectinatus*

The "enrichment" of hypolimnetic waters (with nutrients, metals, and other pollutants) during stratification results from the entrapment of materials that sink down from above, as well as materials that are released from lake sediments due to anoxic conditions. The proportion of each depends on the strength and duration of stratification, existing lake sediment quality, and the inflow of materials from the watershed.

Sediment re-release of materials, and water quality impact at turnover, would be most pronounced in a deep, moderate-to-small sized lake, with abundant protection from the wind, shallow thermocline, and a history of high pollutant loads from the watershed. For the majority of our larger lakes in Kansas, built on major rivers with dependable flow, stratification tends to be intermittent (polymictic), or missing, and the volume of the hypolimnion tends to be small in proportion to total lake volume. These conditions tend to lessen the importance of sediment re-release of pollutants in the largest Kansas lakes, leaving watershed pollutant inputs as the primary cause of water quality problems.

Presence or absence of stratification is determined by the depth profiles taken in each lake for temperature and dissolved oxygen concentration. Table 7 presents this data. Temperature changes (for the entire water column) greater than -1.0°C/m are considered evidence of strong thermal stratification (Hutchinson, 1957; Wetzel, 1983), although temperature changes may be less pronounced during the initiation phase of stratification. Presence of a significant oxycline is also used to verify stratification.

Table 7. Lake stratification status for the 36 lakes surveyed during 1998. The term "na" indicates that boat access, wind conditions, shallowness, or equipment problems prevented taking profile data or made its acquisition superfluous.

Lake	**Date Sampled**	**Temperature Decline Rate (degree C/meter)**	**Dissolved Oxygen Decline Rate (mg/L/meter)**	**Thermocline Depth (meters)**	**Maximum Lake Depth (meters)**
Atchison Co. Lake	7-21-98	na	na	none	1.5
Augusta City Lake	6-8-98	0.00	0.20	none	5.5
Banner Creek Lake	7-21-98	1.15	0.72	4-5	10.0
Big Hill Lake	6-23-98	0.96	0.65	6-8	16.0
Cedar Creek Lake	8-10-98	0.63	0.95	3-4	8.0
Centralia Lake	8-18-98	0.56	1.30	2-3	8.0
Cheney Lake	6-4-98	0.09	0.58	none	11.0
Clinton Lake	6-16-98	0.10	0.18	none	11.0
Council Grove City Lake	6-29-98	0.88	0.61	7-10	12.0
Douglas Co. SFL	7-20-98	1.70	0.87	4-5	10.0
Elk City Lake	6-22-98	0.21	0.56	none	8.0
Fall River Lake	6-22-98	0.33	0.99	4-6	7.5
Gardner City Lake	7-20-98	1.55	0.74	4-5	11.0
Geary Co. SFL	6-29-98	1.25	0.60	6-8	12.0
Hamilton Co. SFL	8-25-98	0.00	0.75	none	2.0
Harvey Co. East Lake	6-9-98	0.25	0.08	none	5.0
Hillsdale Lake Sta. 1 (main body)	7-8-98	0.64	0.66	5-7	14.0

Lake	Date Sampled	Temperature Decline Rate (degree C/meter)	Dissolved Oxygen Decline Rate (mg/L/meter)	Thermocline Depth (meters)	Maximum Lake Depth (meters)
Hillsdale Lake Sta. 2 (Big Bull Arm)	7-8-98	0.83	0.90	4-6	12.5
Hillsdale Lake Sta. 3 (Little Bull Arm)	7-8-98	0.61	0.93	4-6	9.0
Kirwin Lake	7-14-98	0.46	0.52	6-8	15.0
Lake Crawford	7-28-98	0.04	0.32	none	16.0
Lovewell Lake	7-13-98	0.28	0.66	none	9.0
Lyon Co. SFL	6-30-98	1.25	2.11	5-6	8.0
Madison City Lake	6-8-98	0.80	0.78	5-6	10.0
Milford Lake	7-6-98	0.28	0.46	none	18.0
Mission Lake	7-21-98	0.33	1.03	none	4.0
Moline City Lake #2	7-27-98	0.46	1.00	3-4	6.5
Norton Lake	7-13-98	0.75	0.88	6-8	12.0
Olpe City Lake	6-8-98	0.00	0.03	none	5.0
Perry Lake	6-16-98	0.14	0.24	none	16.0
Pottawatomie Co. SFL #1	6-15-98	0.4	1.48	4-5	5.0
Pottawatomie Co. SFL #2	6-15-98	0.8	0.87	5-7	11.0
Sedan North Lake	7-27-98	2.36	1.44	4-5	5.5
Thayer New Lake	7-27-98	2.17	0.83	4-5	9.0
Toronto Lake	6-22-98	0.1	0.94	none	5.5

Lake	Date Sampled	Temperature Decline Rate (degree C/meter)	Dissolved Oxygen Decline Rate (mg/L/meter)	Thermocline Depth (meters)	Maximum Lake Depth (meters)
Tuttle Creek Lake	7-6-98	0.47	0.21	none	16.0
Waconda Lake	7-14-98	0.29	0.61	6-8	14.0
Yates Center Lake	8-17-98	1.06	0.72	2-3	8.5

Fecal Coliform Counts

Since 1996, bacterial sampling has taken place at the primary water quality sampling station at each lake. While many Kansas lakes have swimming beaches, many do not. However, presence or absence of a swimming beach does not determine whether or not a lake has contact recreational use. Contact recreation is defined as, "recreation where the body is immersed in surface water to the extent that some inadvertent ingestion of water is probable" (KDHE, 1994), which includes swimming, water skiing, wind surfing, jet skiing, diving, and other similar activities. The majority of Kansas lakes have some form of contact recreation taking place during the warm half of the year. While sampling of swimming beaches should be conducted to document water quality where people are concentrated in a small area, the entities that manage these lakes day-to-day should be the party responsible for such sampling. They are in a better position to collect samples frequently enough to satisfy the letter of the regulations.

Given the rapid die-off of fecal coliform bacteria in the aquatic environment, due to protozoan predation and a generally hostile set of environmental conditions, high fecal coliform bacterial counts should only occur in the open water of a lake if 1) there has been a recent pollution event, or 2) there is a chronic input of bacteria-laced pollution. Given such a setting, a single set of bacterial samples should be reasonably representative of whole-lake bacterial water quality at the time of the survey. If anything, samples from the open, deep-water environment of a lake should represent the lowest potential bacterial counts one might encounter.

Table 8 presents the bacterial data collected during the 1998 sampling season. All counts are compared to the 200 colonies/100 mL standard for contact recreation within the Kansas Surface Water Quality Standards (KDHE, 1994).

Sixteen lakes, out of the 36 lakes surveyed, had mean fecal coliform bacterial counts greater than the detection limit. No lake in 1998 exceeded the contact recreation criteria.. As mentioned earlier in the report, the summer of 1998 was very dry, with prolonged periods of no rainfall or runoff. These climatic conditions undoubtedly contributed to the lower, overall, bacterial counts.

Four lakes did have fecal coliform counts high enough to at least warrant some discussion. Big Hill Lake and Lake Crawford had counts in the 30's, which are higher than would normally be expected in an open water lake environment but well below the applicable criteria. An aeration system has been initiated at Lake Crawford since the last survey. The aeration lines lie along the substrate, and may recycle bacteria contained in the top sediment layer. Big Hill Lake has been the location of unexplained high bacteria counts in the past. A satisfactory explanation has never been found for bacteria detections at Big Hill Lake. The fecal coliform count at Douglas Co. SFL also lacks a good explanation but, at the time of the survey, it was noted that the lake surface had a substantial covering of grass clippings. It is within the realm of possibility that mowing introduced fecal material located along the shore from wildlife and/or pets (brought to the lake by recreating people). Lovewell Lake's high bacterial counts can likely be attributed to the large volume of inflow occurring at the time of the survey.

Table 8. Fecal coliform bacterial counts (mean of duplicate samples) from the 36 lakes surveyed during 1998. Note: These samples were collected during the week, not during weekends, when recreational activity would be at peak levels. All units are in "number of colonies/100 mL of lake water."

Lake	Site Location	Fecal Coliform Count
Atchison Co. Lake	off dam	20
Augusta City Lake	open water	18
Banner Creek Lake	not sampled	-
Big Hill Lake	open water	35
Cedar Creek Lake	open water	10
Centralia Lake	open water	<10
Cheney Lake	open water	<10
Clinton Lake	open water	<2
Council Grove City Lake	open water	<2.5
Douglas Co. SFL	open water	96.5
Elk City Lake	open water	<10
Fall River	open water	<10
Gardner City Lake	open water	13
Geary Co. SFL	open water	2.5
Hamilton Co. SFL	open water	10
Harvey Co. East Lake	open water	3
Hillsdale Lake Sta. 1 (main body)	open water	<1
Hillsdale Lake Sta. 2 (Big Bull Arm)	open water	<1
Hillsdale Lake Sta. 3 (Little Bull Arm)	open water	<1
Kirwin Lake	open water	<2
Lake Crawford	open water	39
Lovewell Lake	open water	166
Lyon Co. SFL	open water	2
Madison City Lake	open water	<2
Milford Lake	open water	<1

Lake	Site Location	Fecal Coliform Count
Mission Lake	open water	<3.5
Moline City Lake #2	open water	<2
Norton Lake	open water	<2
Olpe City Lake	open water	<10
Perry Lake	open water	6
Pottawatomie Co. SFL #1	open water	5
Pottawatomie Co. SFL #2	open water	<2
Sedan North Lake	open water	<3
Thayer New Lake	open water	<2
Toronto Lake	open water	<10
Tuttle Creek Lake	open water	5
Waconda Lake	open water	<2
Yates Center Lake	open water	15

Limiting Nutrients and Physical Parameters

The determination of which nutrient, or physical characteristic, "limits" phytoplankton production is of primary importance in lake management. If certain features can be identified, which exert exceptional influence on lake water quality, those features can be addressed in lake protection plans to a greater degree than less important factors. In this way, lake management can be made more efficient.

The concept of limiting nutrients, or limiting factors, is often difficult for the layman to grasp. The following analogy is provided in an attempt to clarify the concept.

> A person is given 10 spoons, 9 knives, and 5 forks. They are then asked to place sets of utensils at each seat at a table. Further, only complete sets of utensils are to be placed, with a complete set consisting of all three utensils. The question is, "What utensil is the limiting factor in this situation?"
>
> In this example, the number of available forks "limits" the number of place settings that can be made. So, "forks" is the "limiting factor" for this scenario.

In a lake ecosystem, the level of algal production is the place setting, while plant nutrients and light availability are the spoons, knives, and forks. Common factors that limit algal production in lakes are the level of available nutrients (phosphorus and nitrogen, primarily), and the amount of light available in the water column for phototsynthesis. Less common limiting factors in lakes, and other lentic waterbodies, include available levels of carbon, iron, temperature, trace elements (such as molybdenum or vitamins), or hydrologic flushing rate.

Nutrient ratios are commonly employed in determining which major plant nutrients are limiting factors in lakes. These ratios take into account the relative needs of algae for the different chemical elements versus availability in the environment. Typically, total nitrogen/total phosphorus (TN/TP) mass ratios above 12 indicate increasing phosphorus limitation. Conversely, TN/TP ratios of less than 7 indicate increasing importance of nitrogen. Ratios of 7-to-12 indicate that both nutrients, or neither, may limit algal production (Wetzel, 1983).

Table 9 presents limiting factor determinations for the lakes surveyed during 1998. It should be kept in mind that these determinations reflect the time of sampling, which is chosen to reflect average conditions during the summer growing season to the extent possible, but may be less applicable to other times of the year. There is, however, always the chance that conditions during one survey will differ from conditions during past surveys, despite efforts to sample during times representative of "normal" summer conditions. If such a situation is suspected, it will be noted in Table 9.

As can be seen in Table 9, phosphorus is the primary limiting factor identified for the 36 lakes surveyed in 1998. Twenty-four of the 36 lakes (67%) were determined to be primarily limited by phosphorus. Phosphorus was determined to be the sole limiting factor of significance in 20 lakes (56%). Six lakes (17%) were determined to be primarily nitrogen limited, or co-limiting with phosphorus. The remaining six lakes were determined to be primarily limited by light availability (17%), although one stood out as particularly strongly light limited (Tuttle Creek Lake). Light limited systems were primarily larger federal reservoirs that are constructed on major rivers.

Six additional metrics, in addition to nutrient ratios, are considered to help determine the relative roles of light and nutrient limitation for lakes in Kansas. These metrics, and their description, follow (Walker, 1986; Scheffer, 1998).

1) Non-Algal Turbidity = $(1/SD)-(0.025m^2/mg*C)$,

where SD = Secchi depth in meters and C = chlorophyll-a in mg/m^3.

Non-algal turbidity values $<0.4\ m^{-1}$ tend to indicate very low levels of suspended silt and/or clay, while values $>1.0\ m^{-1}$ indicate that inorganic particles are important in creating turbidity. Values between 0.4 and $1.0\ m^{-1}$ describe a range where inorganic turbidity assumes greater importance as the value increases, but would not assume a significant limiting role until values exceed $1.0\ m^{-1}$.

Table 9. Limiting factor determinations for the 36 lakes surveyed during 1998. NAT = non-algal turbidity, TN/TP = nitrogen-to-phosphorus ratio, Z_{mix} = depth of mixed layer, Chl-a = chlorophyll-a, and SD = Secchi depth. N = nitrogen, P = phosphorus, and L = light. Shading = calculated light attenuation coefficient times mean lake depth.

Lake	TN/TP	NAT	Z_{mix}*NAT	Chl-a*SD	Chl-a/TP	Z_{mix}/SD	Shading	Factors
Atchison Co. Lake	4.1	1.37	0.39	18.04	0.27	0.72	1.28	N≥P
Augusta City Lake	15.2	1.12	2.50	15.43	0.55	4.07	4.60	P
Banner Creek Lake	18.8	0.11	0.39	32.03	0.52	1.96	4.71	P
Big Hill Lake	40.5	0.24	1.30	20.39	0.45	2.64	7.77	P
Cedar Creek Lake	4.8	0.71	2.11	21.89	0.60	4.65	6.10	P=N
Centralia Lake	13.5	<0.10	<0.10	78.00	0.92	3.42	8.14	P
Cheney Lake	3.7	2.38	9.99	1.94	0.04	10.50	9.04	L>N
Clinton Lake	16.2	0.50	2.09	24.57	0.78	5.42	8.48	P
Council Grove City Lake	<5.3	0.42	1.60	14.17	0.35	2.47	4.91	P≥N
Douglas Co. SFL	28.4	0.70	2.42	20.56	1.22	4.97	6.74	P
Elk City Lake	15.8	4.30	13.76	2.20	0.10	14.56	9.76	L>P
Fall River Lake	14.4	3.25	9.81	3.56	0.20	10.76	7.91	L>P
Gardner City Lake	29.5	0.41	1.48	16.56	0.55	2.52	4.84	P
Geary Co. SFL	8.5	0.62	2.35	13.54	0.46	3.56	5.64	P≥N
Hamilton Co. SFL	21.0	<0.10	<0.10	41.37	0.31	0.70	1.63	P
Harvey Co. East Lake	18.8	0.15	0.31	37.20	0.68	4.38	6.20	P
Hillsdale Lake (whole lake)	29.7	0.22	1.10	29.30	0.65	4.10	8.94	P

Lake	TN/TP	NAT	Z_{mix}*NAT	Chl-a*SD	Chl-a/TP	Z_{mix}/SD	Shading	Factors
Hillsdale Lake (main body)	40.9	0.21	1.07	23.68	0.49	2.62	7.11	P
Hillsdale Lake (Big Bull Arm)	26.8	0.53	2.44	25.46	0.77	6.70	10.47	P
Hillsdale Lake (Little Bull Arm)	21.5	0.38	1.33	24.12	0.60	3.36	5.80	P
Kirwin Lake	26.4	0.41	2.16	18.22	0.26	3.96	8.42	P
Lake Crawford	3.0	0.45	1.98	18.48	0.23	3.67	6.81	N≥P
Lovewell Lake	8.0	1.28	4.57	8.18	0.10	5.74	6.36	N≥(P=L)
Lyon Co. SFL	<8.0	0.76	2.27	9.14	0.50	2.95	4.14	(P≥N)>L
Madison City Lake	42.3	0.66	2.26	12.03	0.47	3.24	4.92	P
Milford Lake	13.9	0.22	1.29	24.88	0.17	3.41	9.65	N≥P
Mission Lake	4.8	1.90	3.14	8.90	0.22	4.04	3.80	N≥(P>L)
Moline City Lake #2	<16.0	0.37	0.95	8.10	0.31	1.19	2.72	P
Norton Lake	21.6	0.81	3.62	11.30	0.30	5.04	7.43	P
Olpe City Lake	7.3	4.73	9.74	2.13	0.11	10.29	6.66	L>(N=P)
Perry Lake	13.5	0.42	2.28	20.76	0.35	4.73	9.78	P
Pottawatomie Co. SFL #1	19.4	0.54	1.11	15.39	0.43	1.81	2.90	P
Pottawatomie Co. SFL #2	>36.0	0.21	0.78	13.07	0.46	1.15	3.77	P
Sedan North Lake	<8.0	0.87	1.95	6.94	0.41	2.36	3.10	P≥N
Thayer New Lake	>16.0	0.24	0.76	6.73	0.21	0.91	3.11	P
Toronto Lake	12.7	3.06	6.68	5.75	0.24	7.80	5.97	L>P

Lake	TN/TP	NAT	Z_{mix}*NAT	Chl-a*SD	Chl-a/TP	Z_{mix}/SD	Shading	Factors
Tuttle Creek Lake	12.4	4.26	23.18	0.83	0.01	23.67	18.71	L>(P=N)
Waconda Lake	15.2	0.12	0.61	33.52	0.54	3.76	8.87	P
Yates Center Lake	>32.0	0.52	1.60	11.71	1.71	2.26	3.94	P

Criteria Table

Expected Lake Condition	TN/TP	NAT	Z_{mix}*NAT	Chl-a*SD	Chl-a/TP	Z_{mix}/SD	Shading
Phosphorus Limiting	>12				>0.40		
Nitrogen Limiting	<7				<0.13		
Light/Flushing Limited		>1.0	>6	<6	<0.13	>6	>16
High Algae-to-Nutrient Response		<0.4	<3	>16	>0.40	<3	
Low Algae-to-Nutrient Response		>1.0	>6	<6	<0.13	>6	
High Inorganic Turbidity		>1.0	>6	<6		>6	>16
Low Inorganic Turbidity		<0.4	<3	>16		<3	<16
High Light Availability			<3	>16		<3	<16
Low Light Availability			>6	<6		>6	>16

2) Light Availability in the Mixed Layer = Z_{mix}*Non-Algal Turbidity,

where Z_{mix} = depth of the mixed layer, in meters, and non-algal turbidity refers to the previous metric.

Values <3 indicate abundant light, within the mixed layer of a lake, and a high algal response to nutrients. Values >6 indicate the opposite.

3) Partitioning of Light Extinction Between Algae and Non-Algal Turbidity = Chl-a*SD,

where Chl-a = chlorophyll-a in mg/m^3 and SD = Secchi depth in meters.

Values <6 indicate that inorganic turbidity dominates light extinction in the water column and there is a weak algal response to changes in nutrient levels. Values >16 indicate the opposite.

4) Algal Use of Phosphorus Supply = Chl-a/TP,

where Chl-a = chlorophyll-a in mg/m^3 and TP = total phosphorus in mg/m^3 .

Values <0.13 indicate a low algal response to phosphorus, indicating that nitrogen or light may be important. Values above 0.4 indicate a strong algal response to changes in phosphorus level. The range between 0.13-to-0.4 suggests various levels of moderate algal/phosphorus response.

5) Light Availability in the Mixed Layer for a Given Surface Light = Z_{mix}/SD.

where Z_{mix} = depth of the mixed layer, in meters, and SD = Secchi depth in meters.

Values <3 indicate that light availability is high and algal response to changes in nutrient levels is high. Values >6 indicate the opposite.

6) Shading in Water Column due to Algae and Inorganic Turbidity = Z_{mean}*E,

where Z_{mean} = mean lake depth, in meters, and E = calculated light attenuation coefficient, in units of m^{-1}, derived from Secchi depth and chlorophyll-a data..

Values >16 indicate high levels of shading due to algae and inorganic turbidity in the water column. Values <16 indicate that shading of algae does not significantly impede productivity. The metric is most applicable to lakes with maximum depths less than 5 meters.

In identifying the limiting factors for lakes during 1998, primary importance was given to the 1998 metrics. However, past Secchi depth and chlorophyll-a data were also used in comparison to 1998 data. Additionally, mean and maximum lake depth were taken into account when ascribing the importance of non-algal turbidity. Lakes with fairly high non-algal turbidity may have little real impact from that turbidity if the entire water column can rapidly circulate, bringing algae quickly back to the surface and sunlight (Scheffer, 1998)

Surface Water Exceedences of State Water Quality Criteria

Most numeric and narrative water quality criteria referred to in this section are taken from Chapter 28 of the Kansas Administrative Regulations (K.A.R. 28-16-28b through K.A.R. 28-16-28f), or from EPA water quality criteria guidance documents (EPA, 1972, 1976; KDHE, 1994) for ambient waters and finished drinking water. However, criteria for some metal parameters are based on criteria for dissolved metals promulgated by EPA under the National Toxics Rule. Copies of the Standards may be obtained from the Bureau of Water, KDHE, Building 283, Forbes Field, Topeka, Kansas 66620.

Tables 11, 12, and 13 present documented exceedences of surface water quality criteria and goals during the 1998 sampling season. These data were generated by comparison of a computer data retrieval, for the 1998 Lake and Wetland Monitoring Program ambient data, to the state surface water quality standards and other federal guidelines. Only those samples collected from a depth of 3.0 meters, or less, were used to document standards violations, as a majority of those samples collected from below 3.0 meters were from hypolimnetic waters. In Kansas, lake hypolimnions generally constitute a small percentage of total lake volume and, while usually having more pollutants present in measurable quantities, compared to overlying waters, do not generally pose a significant water quality problem for the lake as a whole.

Eutrophication criteria in the Kansas Surface Water Quality Standards are narrative rather than numeric. This is partially due to the fact that the trophic state of any individual lake reflects a number of site-specific and regional environmental characteristics, combined with pollutant inputs from its watershed. However, lake trophic state does exert a documented impact on various lake uses. The system on the following page (Table 10) has been developed over the last nine years to define how lake trophic status influences the various designated uses of Kansas lakes (EPA, 1990; NALMS, 1992). These trophic state/use support combinations are joined with the site-specific lake trophic state designations to determine expected use support levels at each lake.

With respect to the aquatic life support use, eutrophication and low dissolved oxygen within the upper 3.0 meters comprised the primary water quality concerns during 1998 (Table 11). Twelve lakes exhibited trophic states high enough to impair long or short term aquatic life support. Nine lakes had low dissolved oxygen conditions within the top 3.0 meters of the water column. Only one lake in 1998 exhibited atrazine levels high enough to exceed the interim chronic aquatic life support criterion (3.0 ppb). Two lakes exhibited such high chronic turbidity that community structure and function were deemed affected. These results are very similar to those from 1997.

Eutrophication exceedences are primarily due to excessive nutrient inputs from lake watersheds. Dissolved oxygen problems may be due to trophic state, in part, but were also observed in lakes that did not exhibit excessive trophic state conditions. In these cases, the low dissolved oxygen levels likely result from shallow stratification conditions.

Table 10. Lake use support determination based on lake trophic state (Also see the Appendix.).

Designated Use	A	M	SE	E	VE	H-no BG TSI 64-70	H-no BG TSI 70+	H-with BG TSI 64+
Aquatic Life Support	X	Full	Full	Full	Partial	Partial	Non	Non
Drinking Water Supply	X	Full	Full	Partial	Partial	Non	Non	Non
Contact Recreation	X	Full	Full	Partial	Partial	Non	Non	Non
Non-Contact Recreation	X	Full	Full	Full	Partial	Partial	Non	Non
Livestock Water Supply	X	Full	Full	Full	Partial	Partial	Non	Non
Irrigation	X	Full	Full	Full	Partial	Partial	Non	Non
Groundwater Recharge	Not generally applicable to this use.							
Food Procurement	Applicable to this use, but not directly.							

BG = blue-green algae dominate the community (50%+ as cell count and/or 33%+ as biovolume)
X = use support assessment based on nutrient load and water clarity, not algal biomass

A = argillotrophic (high turbidity lake)
M = mesotrophic (includes OM, oligo-mesotrophic, class), TSI = zero-to-49.9
SE = slightly eutrophic, TSI = 50-to-54.9
E = eutrophic (fully eutrophic), TSI = 55-to-59.9
VE = very eutrophic, TSI = 60-to-63.9
H = hypereutrophic, TSI $\geq$ 64

TSI = 64 = chlorophyll-a of 30 ug/L
TSI = 70 = chlorophyll-a of 56 ug/L

There were 26 exceedences of water supply criteria during 1998 (Table 12). The majority were for eutrophication related conditions (85%). Of these 26 exceedences, only 13 occur in lakes that currently serve as public water supplies (50%). Irrigation use criteria were exceeded in 12 lakes, but only one of those lakes currently is designated for irrigation supply. Twelve lakes also saw exceedences of livestock water criteria, but again, only one is currently a source for livestock water.

Table 11. Chemical and biological parameters not complying with chronic and acute aquatic life support (ALS) criteria in lakes surveyed during 1998. Atz = atrazine, DO = dissolved oxygen, EN = eutrophication and/or high nutrient load, Cl = chloride, and TN = high turbidity and nutrient load. Only those lakes with some documented water quality problem are included in Tables 11, 12, and 13.

	Chronic ALS					Acute ALS		
Lake	**pH**	**DO**	**EN**	**TN**	**Atz**	**Cl**	**EN**	**TN**
Atchison Co. Lake			X				X	
Augusta City Lake			X					
Cedar Creek Lake		X	X					
Centralia Lake	X	X	X				X	
Cheney Lake				X				X
Clinton Lake			X					
Douglas Co. SFL			X					
Hamilton Co. SFL		X	X			X	X	
Harvey Co. East Lake			X		X		X	
Hillsdale Lake			X				X	
Lake Crawford		X						
Lovewell Lake		X						
Mission Lake		X	X					
Norton Lake		X						
Sedan North Lake		X						
Toronto Lake			X					
Tuttle Creek Lake				X				X
Waconda Lake			X					
Yates Center Lake		X						

Table 12. Exceedence of human use criteria and/or EPA guidelines within the surface waters of the lakes surveyed during 1998. Atz = atrazine, Cl = chloride, SO_4 = sulphate, and EN = high trophic state and nutrient loads. Only lakes with documented exceedences are included within the table. An "X" indicates that the exceedence occurred for a presently designated use. An "O" indicates that the exceedence occurred where the indicated use has not yet been determined.

	Water Supply				Irrigation	Livestock Water	
Lake	**Cl**	**SO_4**	**EN**	**Atz**	**EN**	**EN**	**SO_4**
Atchison Co. Lake			O		O	X	
Augusta City Lake			X		O	O	
Banner Creek Lake			X				
Cedar Creek Lake			X		O	O	
Centralia Lake			O		O	O	
Clinton Lake			X		O	O	
Douglas Co. SFL			O		O	O	
Fall River Lake			X				
Geary Co. SFL			O				
Hamilton Co. SFL	O	O	O		O	O	O
Harvey Co. East Lake			O	O	O	O	
Hillsdale Lake			X		O	O	
Kirwin Lake			O				
Lake Crawford			O				
Lovewell Lake			O				
Milford Lake			X				
Mission Lake			X		O	O	
Norton Lake			X				
Perry Lake			X				
Pottawatomie Co. SFL #1			O				
Toronto Lake			X		O	O	
Waconda Lake		X	X		X	O	

Table 13. Exceedences for applicable numeric and narrative water quality criteria for the lakes surveyed during 1998 as regards recreational uses. Contact recreation refers to recreation where accidental ingestion of lake water is likely. Non-contact recreation forms involve a low likelihood of accidental ingestion of lake water. EN = high trophic state and nutrient loads and TN = high turbidity and nutrient loads. An "X" indicates that the use is currently designated for that lake while an "O" indicates that the exceedence occurred where the indicated use has not yet been determined.

	Contact Recreation		Non-Contact Recreation	
Lake	**EN**	**TN**	**EN**	**TN**
Atchison Co. Lake	O		X	
Augusta City Lake	X		X	
Banner Creek Lake	X			
Cedar Creek Lake	O		X	
Centralia Lake	X		X	
Cheney Lake		X		X
Clinton Lake	X		X	
Douglas Co. SFL	O		X	
Fall River Lake	X			
Geary Co. SFL	O			
Hamilton Co. SFL	O		X	
Harvey Co. East Lake	X		X	
Hillsdale Lake	X		X	
Kirwin Lake	X			
Lake Crawford	X			
Lovewell Lake	X			
Milford Lake	X			
Mission Lake	X		X	
Norton Lake	X			
Perry Lake	X			
Pottawatomie Co. SFL #1	O			
Toronto Lake	X		X	

Lake	Contact Recreation		Non-Contact Recreation	
	EN	TN	EN	TN
Tuttle Creek Lake		X		X
Waconda Lake	X		X	

Table 13 shows that there were a total of 24 lakes with trophic state conditions high enough to impair contact recreational uses. Of these, 18 lakes (75%) are currently designated for contact recreation. Fourteen of these lakes had high enough trophic state conditions to impair non-contact recreation uses.

In all, there were 122 exceedences of numeric or narrative criteria, water quality goals, or EPA guidelines documented in Kansas lakes during 1998. Of these, 27% related to aquatic life support, 42% related to consumptive uses, and 31% related to recreational uses. A total of 66% of these exceedences occurred in lakes designated for the particular uses, while 34% of the exceedences occurred in lakes where those particular uses have not yet been verified through use attainability analyses.

Pesticides in Kansas Lakes, 1998

Detectable levels of at least one pesticide were documented in the main body of 20 lakes sampled in 1998 (56% of total). Table 14 lists these lakes and the pesticides that were detected, along with the level detected and the analytical quantification limit. Six different pesticides, and one pesticide degradation byproduct, were detected in 1998. Of these seven compounds only atrazine, metribuzen, and alachlor currently have numeric criteria in place for aquatic life support and/or water supply uses (KDHE, 1994).

Atrazine continues to be the pesticide detected most often in Kansas lakes (KDHE, 1991). Atrazine accounted for 56% of the total number of pesticide detections, and all 20 lakes had some detectable level of atrazine. In addition to atrazine, six lakes had detectable levels of metolachlor (Dual), three had detectable levels of alachlor (Lasso), and one lake each had detections of metribuzen (Sencor or Lexon), cyanazine (Bladex), and acetochlor (Harness or Surpass). Four of the lakes had detectable quantities of the atrazine degradation byproduct deethylatrazine.

In all cases, the presence of these pesticides was directly attributable to agricultural activity. The prolonged dry periods during the summer of 1998 may have prevented there being higher levels of pesticides in these lakes. In only one case did the atrazine concentration exceed the interim chronic aquatic life support or drinking water supply criteria, and this lake is not currently designated for public water supply. Based on the number of different pesticides detected, Tuttle Creek Lake is of most concern (6 detected pesticides). Also of concern, for the same reason, are Atchison Co. Lake, Centralia Lake, Elk City Lake, and Harvey Co. East Lake (3 different pesticides detected in each).

Table 14. Pesticides levels documented during 1998 in Kansas Lakes. All values listed are in ug/L. Analytical quantification limits are as follows: atrazine = 0.3 ug/L, deethylatrazine = 0.3 ug/L, metolachlor = 0.25 ug/L, alachlor = 0.1 ug/L, metribuzen = 0.1 ug/L, cyanazine = 0.5 ug/L, and acetochlor = 0.1 ug/L. Only those lakes with detectable levels of pesticides are reported.

Lake	Pesticide						
	Atrazine	**Deethyl atrazine**	**Metola chlor**	**Ala chlor**	**Metri buzen**	**Cyan azine**	**Aceto chlor**
Atchison Co. Lake	2.70	0.44				2.60	
Big Hill Lake	1.30		0.30				
Centralia Lake	1.60	0.45	0.35				
Clinton Lake	0.48						
Douglas Co. SFL	0.72						
Elk City Lake	1.60		0.64	0.12			
Gardner City Lake	0.43						
Harvey Co. East Lake	4.10		1.90	0.66			
Hillsdale Lake	0.93	0.34					
Lake Crawford	0.74						
Lovewell Lake	0.50						
Lyon Co. SFL	0.43						
Milford Lake	0.60						
Mission Lake	0.56						
Norton Lake	0.36						
Olpe City Lake	0.49						
Perry Lake	0.73						
Toronto Lake	0.65		0.25				
Tuttle Creek Lake	1.10	0.85	4.50	1.20	0.12		0.31
Waconda Lake	0.35						

Discussion of Nonpoint Sources of Pollution for Selected Lakes

Four lakes were chosen for further discussion, based on the number and type of observed surface water quality standard exceedences. A waterbody was chosen if 1) three, or more, parameters exceeded their respective chronic aquatic life support criteria, 2) more than one parameter exceeded applicable acute aquatic life support criteria, or 3) more than one parameter exceeded irrigation, water supply, livestock watering, or recreational criteria. Possible causes and sources of these documented water quality problems are considered below.

1) Centralia Lake receives significant agricultural inputs from its watershed. These inputs include nutrients, silt, and pesticide runoff. Lake trophic state is normally very high during the summer, and enough of the lake is shallow to allow for the development of a significant macrophyte community. Blue-green algae blooms are common throughout the summer months.
2) Hamilton Co. SFL is fed primarily by spring discharge flowing through a small wetland upstream of the lake, but it does receive occasional runoff from its watershed, which is primarily pasture. Water quality problems are largely due to spring/wetland discharge quality and evaporative concentration of spring water within the lake. The shallow nature of the lake exacerbates the development of both a high trophic state and a large macrophyte community.
3) Harvey Co. East Lake receives significant agricultural runoff from its watershed, including nutrients, silt, and pesticides. The watershed is rich in both rowcrop production and small confined animal feeding operations.
4) Waconda Lake is a large federal impoundment that normally maintains a high level of water quality, with the exception of a higher than desirable trophic state. The watershed is primarily cropland, pasture, and rangeland, and the lake is an impoundment of a major Kansas river.

Taste and Odor/Algal Bloom Investigation During 1998

From October 1, 1997 to January 1, 1999, five investigations were undertaken within the auspices of the Taste & Odor/Algae Bloom Program. The results of these investigation are discussed below. Two of the investigations dealt with fishkills, while the other three primarily dealt with aesthetic complaints.

During January, 1998, a number of samples (both chemical and biological) were collected from the stilling basin downstream of the Webster Lake outlet (Rooks Co., Kansas). The stilling basin is a popular local fishing area, and was experiencing a considerable number of dead and diseased fish. No chemical or algal cause was identified. The most likely explanation was a bacterial or fungal disease outbreak.

On June 4, 1998, KDHE Lake and Wetland Program staff surveyed Cheney Lake as part of a fishkill investigation begun by the KDHE Southcentral District Office. The fishkill involved primarily white bass (Morone chrysops). No chemical or algal cause could be identified. It was later indicated that a smaller, but similar, fishkill had occurred the previous year, and the cause was identified as a gill parasite. It was eventually concluded that this year's fishkill resulted from the same cause.

On August 21, 1998, samples were examined in response to a complaint about a "sheen" on the Kansas River near the Johnson Co. Water District #1 intakes. There was no algal cause identified for this surface phenomenon .

On October 21, 1998, samples were collected from Corbin Pond (Butler Co., Kansas) as part of an aesthetic complaint. Apparently, water pumped from a river into fish ponds had overflowed, crossed the property line, and entered Corbin Pond. The specific complaint was concerning a distinct surface scum and "tea" colored water. Samples contained a large amount of macroscopic plant debris, and a very large algae community composed of pennate diatoms and filamentous blue-green algae. The size of the diatom community was the likely cause of the tea colored water.

On November 24, 1998, algae samples were collected from a small lake near a new housing development near Basehor, Kansas (Leavenworth County). The aesthetic complaint described blue-black water color and "sewer" odors. The samples were too turbid to attempt algae counts, but the odor of the sample suggested leaking sewer lines might be the cause of the problem. Subsequent nutrient samples revealed total phosphorus levels of 17-to-21 mg/L, total Kjeldahl nitrogen levels of 93-to-355 mg/L, biochemical oxygen demand of 2,730 mg/L, and total suspended solids levels of 6,200 mg/L. The organic strength of these samples exceeded, by a considerable margin, the values listed in wastewater engineering texts for untreated human sewage. At the time of this writing, an acceptable explanation for the lake condition is still being sought. The most likely explanation may be that this pond was used as a livestock waste lagoon, rather than the watering pond it appeared to be, for a considerable time before housing construction began.

CONCLUSIONS

The following conclusions are offered , based on the lake monitoring data collected during 1998.

1) Trophic state data indicate that 42% of the lakes surveyed in 1998 had degraded since their last survey (i.e., their trophic state had increased). An equal number of lakes, 28% each, indicated either stable or improving trophic state condition.
2) Exceedences of lake use criteria primarily revolved around high lake trophic status (80%), with a smaller group of exceedences due to low dissolved oxygen (7%), high pH (<1%), chloride (<2%), atrazine (<2%), sulphate (2%), and high turbidity (7%). Lake trophic state and turbidity problems resulted primarily from excessive nutrient inputs from nonpoint sources. A smaller portion of the trophic state problems, plus most of the low dissolved oxygen problems, resulted from shallow stratification and/or shallow lake depth.

3) Twenty of the 36 lakes surveyed (56%) had detectable levels of agricultural pesticides. Atrazine was, as in the past, the most frequently detected pesticide. However, most detections were well below applicable criteria.

Conditions described in the three previous paragraphs are, at least partially, attributable to the prolonged hot, dry summer in 1998. These climatologic conditions resulted in increased hydrologic retention times, reduced inflows, and increased evaporation. They also resulted in the majority of lakes experiencing higher water clarity than recorded in the past. Secchi depth readings in 1998 typically ranged from 10-to-50% higher than the mean Secchi depth measured during past surveys.

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LAKE DATA AVAILABILITY

Water quality data are available for all lakes included in the Kansas Lake and Wetland Monitoring Program. These data may be requested by writing to the Bureau of Environmental Field Services, KDHE, Building 283, Forbes Field, Topeka, Kansas 66620-0001. All data referenced within this report are also accessible on the EPA STORET electronic database.

APPENDIX : Lake Trophic State Visual Assessments

INTRODUCTION

The last few years have seen a nationwide movement to accelerate the development of lake/reservoir eutrophication standards. EPA is now in the process of developing ecoregional nutrient criteria that the states will have to adopt by early next century, or face having them promulgated by EPA on their behalf (EPA, 1998). There is fairly unanimous scientific opinion that higher lake trophic state does correspond with increasing levels of lake use impairment (EPA, 1990; NALMS, 1992, KDHE, 1998a; KDHE, 1998b). A number of states currently have narrative eutrophication criteria in their water quality standards, and several states and Canadian provinces have developed numeric eutrophication criteria (EPA, 1990; NALMS, 1992). A study published in 1989 indicated that about 60% of the states indicate they have a need for numeric eutrophication criteria (Johnson, 1989). A number of recent studies have also indicated a strong connection between increasing lake trophic state and loss of economic revenues from lakes (Boyle, et. al., 1997; Jobin, 1997).

Kansas has had a narrative eutrophication criterion in its water quality standards for a number of years. For the last three 305(b) reporting cycles, lake trophic state classification has been used to apply this narrative criterion in assessments of lake use impairment. The validity and value of using non-regulatory numeric criteria to implement a regulatory narrative criterion has been recognized by experts in the area of eutrophication management (Heiskary and Walker, 1988; NALMS, 1992). Table 10 compiles the system that has been used and referenced in recent KDHE documents (KDHE, 1998a; KDHE, 1998b). This system has been derived largely from the standards developed in other states, incorporating those ideas and concepts that are best suited to our geographic region. This appendix examines the results of a recent effort to verify the use of the system outlined in Table 10.

METHODS

During the summer of 1998, KDHE attempted to verify the suitability of the numeric guidelines presented in Table 10 for assessing lake use impairment by eutrophication. The methodology was developed for use in Minnesota, where lake conditions are described in terms of the frequency, or risk of, nuisance conditions (Heiskary and Walker, 1988). The reader is referred to that article for an in-depth discussion of procedures. The basic method involves 1) *a-priori* assessments of lake use support, based on visual inspection, 2) correlating visual assessment data with analytical data for trophic state parameters (nutrients, chlorophyll-a, Secchi depth, and non-algal turbidity), 3) conducting a frequency analysis of the data, and 4) using that frequency analysis to develop criteria based on perceived risk levels (<1%, 10%, 25%, etc.).

Three lake uses were assessed for the study conducted in 1998. These were contact recreation, non-contact recreation, and aesthetic use. Kansas Water Quality Standards do not utilize an "aesthetic" use for surface waters, unlike some neighboring states such as Nebraska. Never-the-less, the aesthetic quality of lakes does exert an impact on other types of use support and even property values (Boyle, et al., 1997). In Kansas, many housing projects have used location near a lake to attract buyers. Lowered water quality in these lakes does have an effect on property buyers and property values. "Aesthetic" assessments of the water, for this study, looked for a lack of an overtly visible algae community and the lack of overtly visible inorganic turbidity. While the model for this effort (Heiskary and Walker, 1988) used frequency analysis to derive phosphorus criteria, KDHE chose to derive primary criteria for algal biomass and water clarity, which are arguably better primary indicators of use impairment statewide. The ultimate source of such impairments (nutrients, particularly phosphorus) are better identified on a lake-specific basis afterward, such as during development of Total Maximum Daily Load (TMDL) proposals. Many states have indicated a similar viewpoint, while many others argue for the primary use of nutrient criteria based on both lake and downstream impacts (EPA, 1998).

While the Minnesota approach utilized only a single visual assessment, focusing on the level of "green" observed in the water, KDHE's study involved two separate assessments, "green" and "brown." These visual assessments relate to impairments resulting from elevated lake trophic state (algal biomass) and reduced levels of water clarity, respectively. In Kansas (as well as throughout the world), traditional water clarity measures, such as Secchi depth and nephelometric turbidity, are influenced more by soil-derived inorganic turbidity than by algae (Davies-Colley, et al., 1993). Given that soil erosion is a major problem in many Kansas watersheds, the use of two visual assessments was deemed valuable.

Staff of the Lake and Wetland Monitoring Program conducted these visual assessments at each waterbody surveyed during the summer of 1998. This resulted in 52 lakes and wetlands being included in the study. At each site, staff would first measure Secchi depth. The visual assessments were conducted by examining the color of the water upon the white quarters of the Secchi disk at a depth of one-half the Secchi depth itself. After examining the color on the Secchi disk, plus assessing the overall appearance of the water column, "green" scores were selected by each staff member for each of the three use categories and "brown" scores were similarly selected. The make-up of the field crew was believed to provide a decent cross-section of viewpoints, in that one staff member grew up in an urban setting in eastern Kansas while the second crew member grew up in a rural western Kansas environment. While this study did not involve a random cross section of the general public, it appeared to provide a reasonable data base for water quality standards development (Smeltzer and Heiskary, 1990; NALMS, 1992). Assigned scores, between field staff, rarely differed by more than one unit, demonstrating a general uniformity of perception among informed observers regardless of background.

Table A1 presents the assessment scoring system for assigning green scores, while A2 presents the scoring system for brown score assignment. In each case, a score of three is meant to represent the onset of minor use impairment (i.e., partial impairment) while a score of five is meant to represent the onset of significant use impairment (i.e., non-support). Only the green or brown quality of the water column was taken into account in assigning scores. Factors such as water depth impact on contact recreation, shoreline condition on aesthetic appeal of the lake, or lack of a boat ramp on non-contact recreation (as three examples) were not considered.

Table A1. "Green" score descriptors for contact and non-contact recreation uses, and for aesthetics. Even scores allowed for maximum flexibility in allowing individuals to interpolate between descriptions. Hesitation about recreating in a given waterbody is based only on the appearance of the water, in terms of algae or "green-ness." Other factors, such as waterbody depth or facilities, were not part of the assessment.

Score	Aesthetic Appearance	Contact Recreation	Non-Contact Recreation
1	Beautiful, no problems.	Beautiful, no problems.	Beautiful, no problems.
2			
3	Not clear. Some algae and color visible.	Slight hesitation about swimming in or contacting water.	Slight hesitation about wading in or boating on water.
4			
5	Definite or strong green algae color.	Definite hesitation about swimming in or contacting water.	Definite hesitation about wading. Some reduced boating quality
6			
7	Very strong green algae color.	Strong hesitation about swimming in or contacting water	Strong hesitation about wading. Quality of boating experience definitely impaired.
8			
9	Extreme green algae color. Scums and/or odors evident.	Contact recreational use enjoyment impossible due to algae levels.	Wading and boating enjoyment almost impossible due to algae.
10			

The frequency/risk potential approach was applied to both sets of scores, for all three uses. The water quality parameters of chlorophyll-a and Secchi depth were used in association with the green visual scores. In a similar fashion, Secchi depth and calculated non-algal turbidity were used in association with brown visual scores. No significant correlation between green scores and non-algal turbidity were discerned, while brown scores did not correlate with chlorophyll-a levels. Total phosphorus was also examined, in comparison to both green and brown scores, as the original Minnesota study had done. For both brown and green scores, the strength of correlation with total phosphorus was less than for Secchi depth or chlorophyll-a, respectively, but still significant.

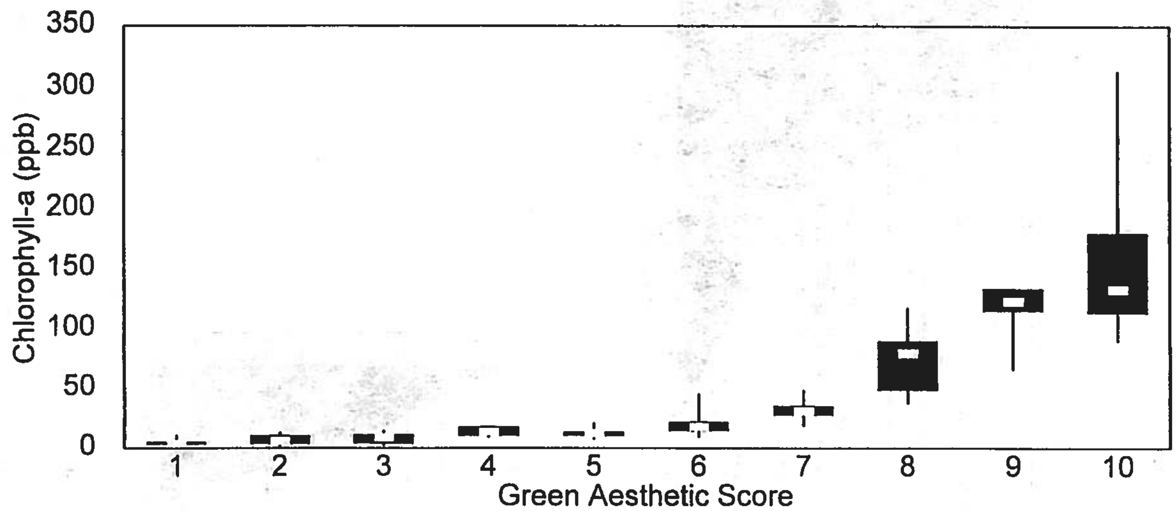
Table A2. "Brown" score descriptors for contact and non-contact recreation uses, and for aesthetics. Even scores allowed for maximum flexibility in allowing individuals to interpolate between descriptions. Hesitation about recreating in a given waterbody is based only on the appearance of the water, in terms of turbidity or "brown-ness." Other factors, such as waterbody depth or facilities, were not part of the assessment.

Score	Aesthetic Appearance	Contact Recreation	Non-Contact Recreation
1	Beautiful, no problems.	Beautiful, no problems.	Beautiful, no problems.
2			
3	Not clear. Some turbidity and color visible.	Slight hesitation about swimming in or contacting water.	Slight hesitation about wading in or boating on water.
4			
5	Definite or strong turbidity/brown color.	Definite hesitation about swimming in or contacting water.	Definite hesitation about wading. Some reduced boating quality
6			
7	Very strong brown turbidity/color.	Strong hesitation about swimming in or contacting water	Strong hesitation about wading. Quality of boating experience definitely impaired.
8			
9	Extreme brown turbidity/color.	Contact recreational use enjoyment impossible due to turbidity levels.	Wading and boating enjoyment almost impossible due to turbidity.
10			

RESULTS

The best relationship, based on scatter plots and regression analyses, were between green scores and chlorophyll-a levels ($0.74 \leq R^2 \leq 0.83$, for the three lake uses). Secchi depth provided a weaker correlation with green scores ($0.13 \leq R^2 \leq 0.23$, for the three lake uses) than did total phosphorus ($0.26 \leq R^2 \leq 0.45$, for the three lake uses). An even weaker relationship was indicated between non-algal turbidity and green scores ($0.00 \leq R^2 \leq 0.03$, for the three lake uses). Relationships were statistically significant ($P < 0.01$) for green scores and chlorophyll-a, total phosphorus, and Secchi depth. Figure A1 shows typical box and whisker plots for green scores and chlorophyll-a for the aesthetic appearance use. Figure A2 shows typical frequency area curves generated for risk potential

Figure A1. Typical box and whisker plots used in the analysis of visual score data. The example given is for green scores and chlorophyll-a concerning the aesthetic appearance of the water. ANOVA tests show that there are significant ($P < 0.01$) differences among the first five groups, as well as among all ten groups.



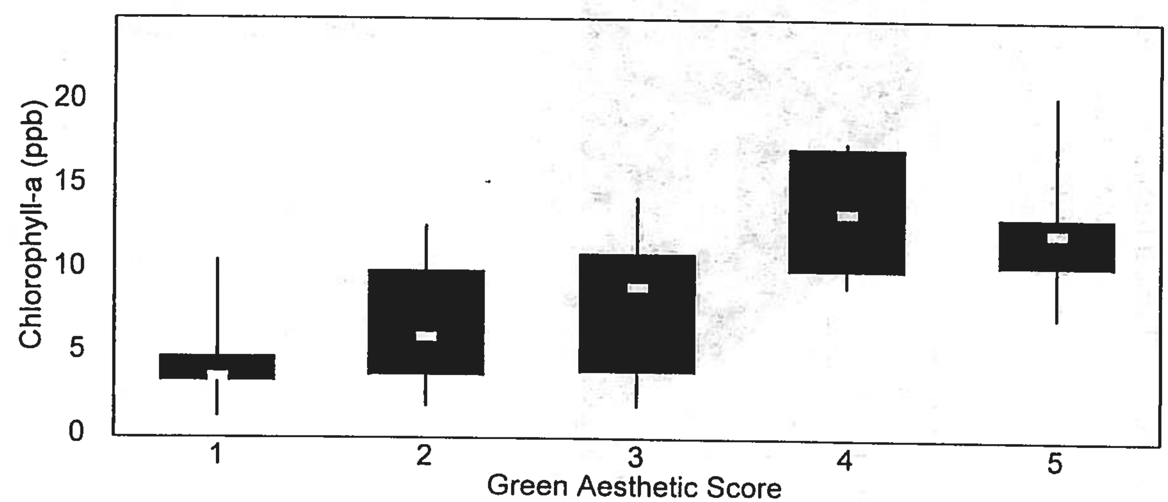
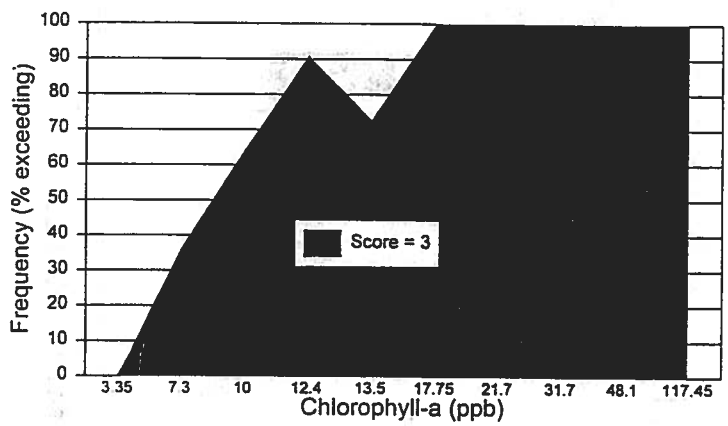
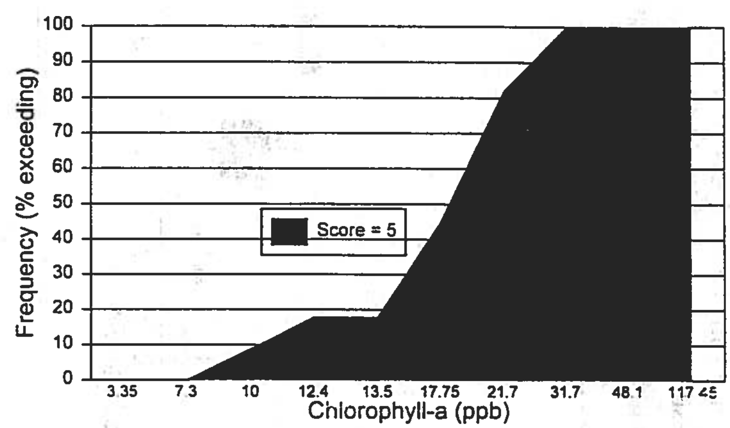
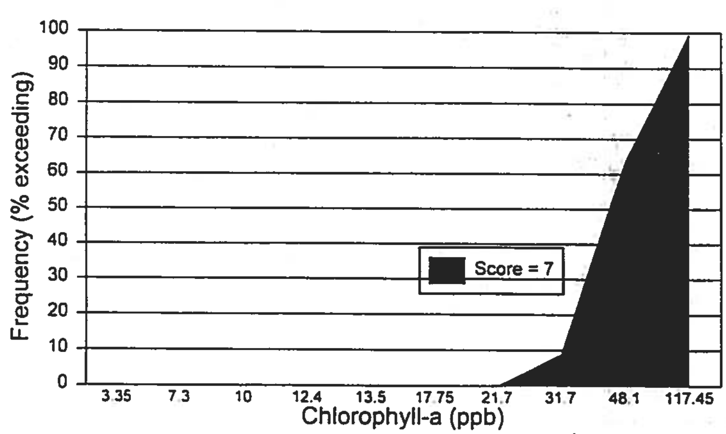


Figure A2. Typical frequency area curves generated during the analysis of the visual score data. These examples are for the green scores and chlorophyll-a levels concerning the aesthetic appearance of the water. The three graphs examine the scores exceeding "3," "5," and "7." respectively.







assessments, for green scores and chlorophyll-a for the aesthetic use category. Over 100 graphs and charts were produced as a part of the data analysis for this study and Figures A1 and A2 are meant only to provide the reader with a general idea of how the data was evaluated.

Brown scores were most strongly correlated with Secchi depth ($0.56 \leq R^2 \leq 0.63$, for the three lake uses) and non-algal turbidity ($0.52 \leq R^2 \leq 0.63$, for the three lake uses). Brown scores correlated slightly less well with total phosphorus ($0.34 \leq R^2 \leq 0.53$, for the three lake uses), while chlorophyll-a did not correlate well with brown scores ($0.01 \leq R^2 \leq 0.06$, for the three lake uses). Relationships were statistically significant ($P < 0.01$) between brown scores and Secchi depth, total phosphorus, and non-algal turbidity.

Based on the array of analyses conducted, chlorophyll-a is a good parameter for assessing lake trophic state impacts on recreational use and user perception. Secchi depth and calculated non-algal turbidity values are about equally good parameters for assessing water clarity impacts on recreational uses and user perceptions. Table A3 lists threshold values, in terms of what chlorophyll-a level marks the onset of use impairment. Tables A4 and A5, respectively, list the Secchi depth and non-algal turbidity levels that mark onset of use impairment.

Table A3. Chlorophyll-a ranges that correspond with <1%, 10%, and 25% risk levels (where <1%, 10%, and 25% of an informed public would perceive a use to be impaired). Chlorophyll-a values are in units of ug/L. The "no swimming" category is based on green scores of seven, while minor and major impairment are based on green scores of three and five, respectively. "Definite" and "high" algae levels equal scores of 5 and 7, respectively.

Impairment Level And Use	**Risk Level**		
	< 1%	**10%**	**25%**
Minor: Aesthetic	3.3	4.5	6.1
Major: Aesthetic	7.3	10.4	14.8
Minor: Contact Recreation	7.3	10.2	16.1
Major: Contact Recreation	17.7	19.0	21.2
No Swimming/Contact	31.7	39.3	50.8
Minor: Non-Contact Recreation	17.7	19.7	24.0
Major: Non-Contact Recreation	21.7	33.0	40.5
Definite Algae Present	7.3	10.4	14.8
High Algae Present	21.7	31.7	35.5

Table A4. Secchi depth ranges that correspond with <1%, 10%, and 25% risk levels (where <1%, 10%, and 25% of an informed public would perceive a use to be impaired). Secchi depth values are in units of centimeters. The "no swimming" category is based on brown scores of seven, while minor and major impairment are based on brown scores of three and five, respectively. "Definite" and "high" turbidity equal scores of 5 and 7, respectively.

Impairment Level And Use	**Risk Level** < 1%	10%	25%
Minor: Aesthetic	106	95	79
Major: Aesthetic	86	78	67
Minor: Contact Recreation	86	78	67
Major: Contact Recreation	86	64	35
No Swimming/Contact	64	47	20
Minor: Non-Contact Recreation	64	59	40
Major: Non-Contact Recreation	64	47	21
Definite Turbidity Present	86	78	67
High Turbidity Present	64	47	22

CONCLUSIONS

KDHE assessments of lake use impairment, performed during the past decade and utilizing techniques common to other states, have employed a threshold of 12.0 ug/L of chlorophyll-a for the onset of partial impairment of contact recreation uses, and a threshold of 20.0 ug/L chlorophyll-a for the onset of non-support. These thresholds correspond with the thresholds for the trophic state classifications of "eutrophic" and "very eutrophic," respectively.

The visual score data appears to validate the use of these numbers for assessing lake use support. Minor impairment of contact recreation (Table A3) begins around the transition from slightly-to-fully eutrophic, between 10 and 16 ug/L of chlorophyll-a. Major impairment of contact recreation occurs between 19 and 21 ug/L of chlorophyll-a.

For the non-contact recreation use, past assessments have used a threshold of 20.0 ug/L chlorophyll-a for the onset of partial impairment, and a threshold of 30.0 ug/L chlorophyll-a for the onset of non-support of the use. These thresholds correspond with the thresholds for "very eutrophic" and

Table A5. Non-algal turbidity ranges that correspond with <1%, 10%, and 25% risk levels (where <1%, 10%, and 25% of an informed public would perceive a use to be impaired). Turbidity values are in units of meters^{-1}. The "no swimming" category is based on brown scores of seven, while minor and major impairment are based on brown scores of three and five, respectively. "Definite" and "high" turbidity equals scores of 5 and 7, respectively.

Impairment Level And Use	Risk Level <1%	10%	25%
Minor: Aesthetic	0.52	0.59	0.83
Major: Aesthetic	0.81	0.88	1.00
Minor: Contact Recreation	0.81	0.85	0.91
Major: Contact Recreation	0.81	0.95	1.94
No Swimming/Contact	1.55	3.40	4.50
Minor: Non-Contact Recreation	0.81	0.91	1.05
Major: Non-Contact Recreation	1.55	2.89	3.83
Definite Turbidity Present	0.81	0.88	1.00
High Turbidity Present	1.55	2.82	3.47

"hypereutrophic," respectively.

Analysis of the visual score data indicates that the use of these numbers for assessing use support is also valid. Minor impairment of non-contact recreation (Table A3) begins around the transition from eutrophic-to-very eutrophic, between 20 and 24 ug/L of chlorophyll-a (within the very eutrophic classification). Major impairment of non-contact recreation occurs between 33 and 40 ug/L of chlorophyll-a (within the hypereutrophic classification).

Kansas lakes have not been assessed previously for "aesthetics," but analysis of visual score data (Table A3) suggests that partial impairment would be noticed by a significant portion of the public at chlorophyll-a levels of 4-to-5 ug/L (mesotrophic classification). Non-support of purely aesthetic uses would be expected at the transition between slightly eutrophic and fully eutrophic (10-to-14 ug/L chlorophyll-a).

Extrapolating to the water clarity visual data, the contact recreation use would likely begin to experience some impairment at Secchi disk values below 78 cm (non-algal turbidity >0.85 m^{-1}), and non-support at Secchi depths below 64 cm (non-algal turbidity >0.95 m^{-1}). The non-contact recreation use would likely experience partial impairment at Secchi depths below 59 cm (non-algal turbidity $>0.91\ m^{-1}$), and non-support would occur at Secchi depths below 47 cm (non-algal turbidity $>2.89\ m^{-1}$). Visual data also suggest that aesthetic uses would begin to show partial impairment at Secchi depths below 95 cm (non-algal turbidity $>0.59\ m^{-1}$) and non-support at Secchi depths below 78 cm (non-algal turbidity $>0.88\ m^{-1}$). These numbers are in general agreement with those few authorities that have published numeric water clarity standards (Davies-Colley, et al., 1993).

Although total phosphorus criteria should be set on a lake-specific basis, the risk based values for this study provide useful general guidelines, similar to those developed for lake management in Minnesota (Heiskary and Walker, 1988). Partial impairment of contact recreation would be expected at total phosphorus levels >20 ug/L and non-support at levels >65 ug/L (using "green" scores versus total phosphorus). Similarly, partial support of non-contact recreation would be expected at total phosphorus levels >77 ug/L, while non-support would be expected at levels >178 ug/L (again, using "green" scores versus total phosphorus). Partial impairment of aesthetics would occur at total phosphorus levels >9 ug/L, with non-support at levels >19 ug/L. "Definite" presence of algae would be expected at any total phosphorus level >20 ug/L.

Overall, visual scoring data validates current techniques for assessing lake use support for eutrophication impacts. Given that this technique shows promise, the KDHE Lake and Wetland Monitoring Program will continue visual score data collection during sampling activities in 1999 in an attempt to add different lakes to the database and further refine the results of the analysis.